Growth and yield models for Dahurian larch plantations

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Abstract Several equations were selected using nonlinear regression analysis for setting up growth and yield models of Dahurian larch (*Larix gmelinii* Rupr.) plantations. Data of 405 stem analysis trees were collected from 336 temporary plots throughout the Daxing'an Mountains. Results showed that the Richards equation was the best model for estimating tree height, stand mean height and stand dominant height by age; the Power equation was the fittest model for predicting tree volume by DBH and tree height, and the Logarithmic stand volume equation was good for predicting stand volume from age, mean height, basal area and other stand variables. These models can be used to construct volume tables, site index table and other forestry tables for Dahurian plantations.

Key words: Growth and yield model, Richards equation, Dahurian larch Plantations, *Larix gmelinii*

Introduction

Dahurian larch (*Larix gmelinii* Rupr.) is one of the most important timber species in China. As a result of over cutting for several decades, the natural Dahurian larch forest resources are declining rapidly. Plantations of dahurian larch have become an important part of forest preserve resources in Daxing'an Mountains. Consequently studying the growth of Dahurian larch and forming the forest tables are of significance to forest production. This paper presents information on growth and yield models of Dahurian larch plantations.

Methods

Data of 405 stem analysis trees were collected from 336 temporary plots throughout Daxing'an Mountains in the Inner Mongolian Autonomous Region, investigated by Neimengol Forestry College, Beijing Forestry University, Northeast Forestry University, Henan Agricultural University and Yakeshi Forestry Administrative Bureau. Summary statistics for sampled stand are presented in Table 1.

According to the previous studies on plantations and growth characteristics of Dahurian larch plantations (Avery 1983; Davis 1987; Jiang 1987), The following equations were used for a growth and yield model of Dahurian larch plantations:

(1) Richards equation: $Y = a(1\text{-}\exp(-kX)^b$

(2) Mitsherlich equation: $Y = M(1 - L\exp(-cX))$

(3) Logarithm equation: $Y = a+bX+c\ln X$

(4) Power equation: $Y = aXb$

(5) Parabola equation: $Y = a+bX+cX^2$

Where: Y, X=growth factors; a, b, c, k, L and M are parameters to be estimated.

Table 1 . Stand attributes statistics of 336 plots

Factors	Min.	Max.	Mean	Standard deviation	CA
A, yr.	6	42	19.7	5.423	0.275
D, cm	1.5	24.5	10.6	3.318	0.313
H, m	2.4	14.7	8.9	2.549	0.286
N, trees·km^{-2}	207	10667	2509	1445.012	0.575
B, m^2·km^{-2}	0.36	53.90	19.99	9.673	0.484
M, m^3·km^{-2}	1.0	259.4	93.55	48.350	0.517

A--Stand age; D--Mean DBH; H--Mean height; N--Number of trees; B--Basal area; M--Stand volume; CA--Coefficient of variation

Results and analysis

Tree growth and yield models:

Using a program written with Marquardt iteration methods (Marquardt 1963) and the data from 405 stem analysis trees, we computed above 5 equations, the results are presented in Table 2. From Table 2, by the standard of maximum of R^2 and the minimum of $S_{y.x}$, the Logarithmic equation is good for estimating DBH by age and estimating age by DBH and height. The Power equation is the best model for predicting volume by age, height and DBH. The Parabola equation is good for estimating height by DBH and age and estimating DBH by tree height. The Richards equation is the fittest model for estimating height by age. With the data of stem analysis, we can use the Power equation to form volume tables and use the Richards equation as a guide curve to construct site index tables.

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Table 2 Tree growth and yield models fitted to data from Dahurian larch plantations

Models	n	R^2	$S_{y.x}$
1. Age and other growth factors			
D=57.65332(1-exp (-0.01267 A))$^{1.038966}$	405	0.5267	3.1160
D=51.53190(1-1.01245exp(-0.01413 A))	405	0.5269	3.1153
D=-5.22557+0.37230 A+3.34276 ln$A$	405	0.5282	3.1109
D=0.78755 $A^{0.91256}$	405	0.5264	3.1134
D=-0.39323+0.70022 A-0.003555A^2	405	0.5268	3.1158
H=19.67586(1-exp(-0.04645 A))$^{1.321796}$	405	0.7005	1.6076
H=21.72092(1-1.06609exp(-0.03456A))	405	0.7003	1.6076
H=-6.25836+0.17221 A+4.30944 ln$A$	405	0.6989	1.6118
H=0.87448 $A^{0.81212}$	405	0.6935	1.6242
H=-0.81122+0.68338 A-0.006851A^2	405	0.7004	1.6078
V=100.37120(1-exp(-0.00235A))$^{2.402588}$	405	0.5170	0.04143
V=1.69475(1-1.04514exp(-0.00430A))	405	0.4736	0.04325
V=0.19707+0.01551 A-0.14868 ln$A$	405	0.5123	0.04162
V=0.0000575 $A^{2.326968}$	405	0.5167	0.04139
V=0.009615-0.00218 A+0.000238A^2	405	0.5171	0.04142
2. DBH and other growth factors			
A=192.78050(1-exp(-0.00134D))$^{0.546246}$	405	0.5388	3.9656
A=38.32072(1-0.88034exp(-0.05165D))	405	0.5377	3.9707
A=2.12356+0.46989D +4.96219 ln$D$	405	0.5393	3.9636
A=5.22059$D^{0.54183}$	405	0.5388	3.9609
A=5.56995+1.46314 D-0.0020956D^2	405	0.5363	3.9763
H=50.52053(1-exp (-0.00824D))$^{0.685649}$	405	0.7559	1.4393
H=18.26356(1-1.00685exp(-0.06845D))	405	0.7695	1.4102
H=-1.30550+0.23118D+4.30944 ln$D$	405	0.7610	1.4360
H=1.98836$D^{0.64906}$	405	0.7577	1.4442
H=0.46115+1.04194D-0.0192752D^2	405	0.7709	1.4061
V=100.26440(1-exp(-0.00335 D))$^{2.21087}$	405	0.8735	0.02119
V=9.56292(1-1.00780exp(-0.00124D))	405	0.8048	0.02634
V=0.05838+0.02151D-0.10353 ln$D$	405	0.8651	0.02190
V=0.0002153$D^{2.245176}$	405	0.8735	0.02118
V=0.000549-0.00158 D+0.000531D^2	405	0.8726	0.02141
3. Height and other growth factors			
A=175.52490(1-exp(-0.00754H))$^{0.824584}$	405	0.6907	3.2475
A=54.55263(1-0.99986exp(-0.04662H))	405	0.6912	3.2450
A=-2.14313+1.04829 H +5.18289 ln$H$	405	0.6916	3.2432
A=3.232736 $H^{0.79516}$	405	0.6905	3.2447
A=0.71453+2.30799H-0.034861H^2	405	0.6808	3.2469
D=271.81090(1-exp(-0.00653 H))^{1124463}	405	0.7337	2.3376
D=95.94006(1-1.011927exp(-0.01561H))	405	0.7334	2.3386
D=-1 88694+1.22700H+0.81352 ln$H$	405	0.7342	2.3351
D=0.99186$H^{1.088765}$	405	0.7337	2.3345
D=-086681+1.29116H+0.015863H^2	405	0.7341	2.3358
V=143.24030(1-exp(-0.00863 H))$^{2.31087}$	405	0.6917	0.03310
V=21.30118(1-1.00416exp(-0.000747H))	405	0.6124	0.03711
V=0.12398+0.03830H-0.19366 ln$H$	405	0.6705	0.03421
V=0.0000581$H^{2.987264}$	405	0.6922	0.03303
V=0.04423-0.01509H+0.001636H^2	405	0.6886	0.03326

Where: A=age (yr.), D=DBH (cm), H=height (m), V=volume (m^3)

Stand growth and yield models

Using the program written with the Marquardt iteration method and 336 plots, we computed equations from (1) to (5), the results are presented in Table 3.

Table 3 Stand growth and yield models fitted to data from Dahurian larch plantations

Models	n	R^2	$S_{y.x}$
1.age and other growth factors			
D=16.39640(1-exp(-0.087937A))$^{2.071432}$	336	0.5824	2.1580
D=17.64273(1-1.30956exp(-0.06263A))	336	0.5848	2.1445
D=-13.08907+0.00317 A+8.02835 ln$A$	336	0.5827	2.1383
D=0.92619$A^{0.818666}$	336	0.5696	2.1802
D=-1.68115+0.81739A-0.009285A^2	336	0.5784	2.4725
H=13.63268(1-exp(-0.09033A))$^{2.089143}$	336	0.6682	1.4725
H=15.10547(1-1.21595exp(-0.05912A))	336	0.6661	1.4772
H=-10.50499-0.02245A+6.63047 ln$A$	336	0.6621	1.4861
H=0.86135$A^{0.787043}$	336	0.6443	1.5235
H=-2.00858+0.77433A-0.010366 A^2	336	0.6671	1.4750
M=289.14210(1-exp(-0.04130A))$^{2.096109}$	336	0.9959	12.5020
M=160.29901(1-1.98072exp(-0.08459A))	336	0.4667	35.4125
M=-291.27980-2.65786A-+148.6801 ln$A$	336	0.4624	35.5538
M=3.51675$A^{1.102217}$	336	0.4125	37.1129
M=-98.77271+14.58654 A-0.22774A^2	336	0.4675	35.3856
H_d=15.51007(1-exp(-0.10022 A))$^{2.193122}$	202	0.7448	1.2133
H_d=16.88736(1-1.28617exp(-0.067342A))	202	0.7415	1.4818
H_d=-13.46869-0.07182 A+8.71854 ln$A$	202	0.7355	1.2253
H_d=1.18026$A^{0.742858}$	202	0.7062	1.2553
H_d=-2.26923+0.93965A-0.01306A^2	202	0.7441	1.2141
2. DBH and other growth factors			
H=16.03795(1-exp(-0.09495D))$^{1.215846}$	336	0.7090	1.3792
H=17.85097(1-1.01957exp(-0.07008D))	336	0.7078	1.3820
H=-8.2840+0.32752D+2.74523 ln$D$	336	0.6980	1.4049
H=1.69373$D^{0.710523}$	336	0.6975	1.4041
H=0.09859+1.13493D-0.024151D^2	336	0.7115	1.3731
H_d=18.76122(1-exp(-0.08479D))$^{0.967996}$	202	0.7089	1.2539
H_d=18.94007(1-0.98091exp(-0.08387D))	202	0.7091	1.5718
H_d=-0.42644+0.26303 D+3.54947 ln$D$	202	0.7025	1.2608
H_d=2.54372$D^{0.626083}$	202	0.6996	1.2623
H_d=1.07968+1.25897D-0.02771D^2	202	0.7107	1.2520
3.models of H and H_d			
H_d=23.21254(1-exp(-0.08494 H))$^{1.21436}$	202	0.8599	0.9705
H_d=26.00418(1-1.03655exp(-0.06388H))	202	0.8599	0.9420
H_d=-1.76030+0.58286H+3.32299 ln$H$	202	0.8948	0.9721
H_d=1.73430$H^{0.82767}$	202	0.8920	0.9773
H_d=-0.57168+1.55616H-0.03204H^2	202	0.8954	0.9709

Where: A=stand age (yr.), D=mean DBH (cm), H=height (m), H_d=dominant height(m), M=volume per hectare($m^3 \cdot km^{-2}$)

From Table 3, we see that the Logarithmic equation is good for estimating DBH by age. The Parabola equation is good for estimating height dominant height

by DBH. The Richard equation is the best model for estimating mean height, dominant height and stand volume by age. The Mitsherlich equation is the fittest model for estimating dominant height by mean height. Thus we can use the Richards equation as a guide curve with the data of temporary plots to construct site index tables.

The model of stand volume related to stand characteristics is as following:

$$M=\exp(1.56473+0.02589H-1.47666/A+0.935181\ \ln G)$$
$$R^2=0.9378,\ S_{y.x}=12.1152,\ N=336$$

Where: A is stand age (yr.); H is height (m); G is basal area per hectare ($m^2 \cdot km^{-2}$); M is volume per hectare, ($m^3 \cdot km^{-2}$)

Conclusion and discussion

In this study, the growth and yield model for Dahurian larch plantations were developed. From the results, we can see that it's better to fit different growth factors with different growth and yield models. For Dahurian larch plantations, the Richards equation is the best model for estimating the tree height, stand mean height and dominant height by age. The Power equation is fit for predicting tree volume from DBH and tree height. The logarithmic stand volume equation is the fittest model for predicting stand volume by age, mean height and basal area per hectare. These models can be used to construct the volume table, the site index table and other forestry tables for Dahurian larch plantations.

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